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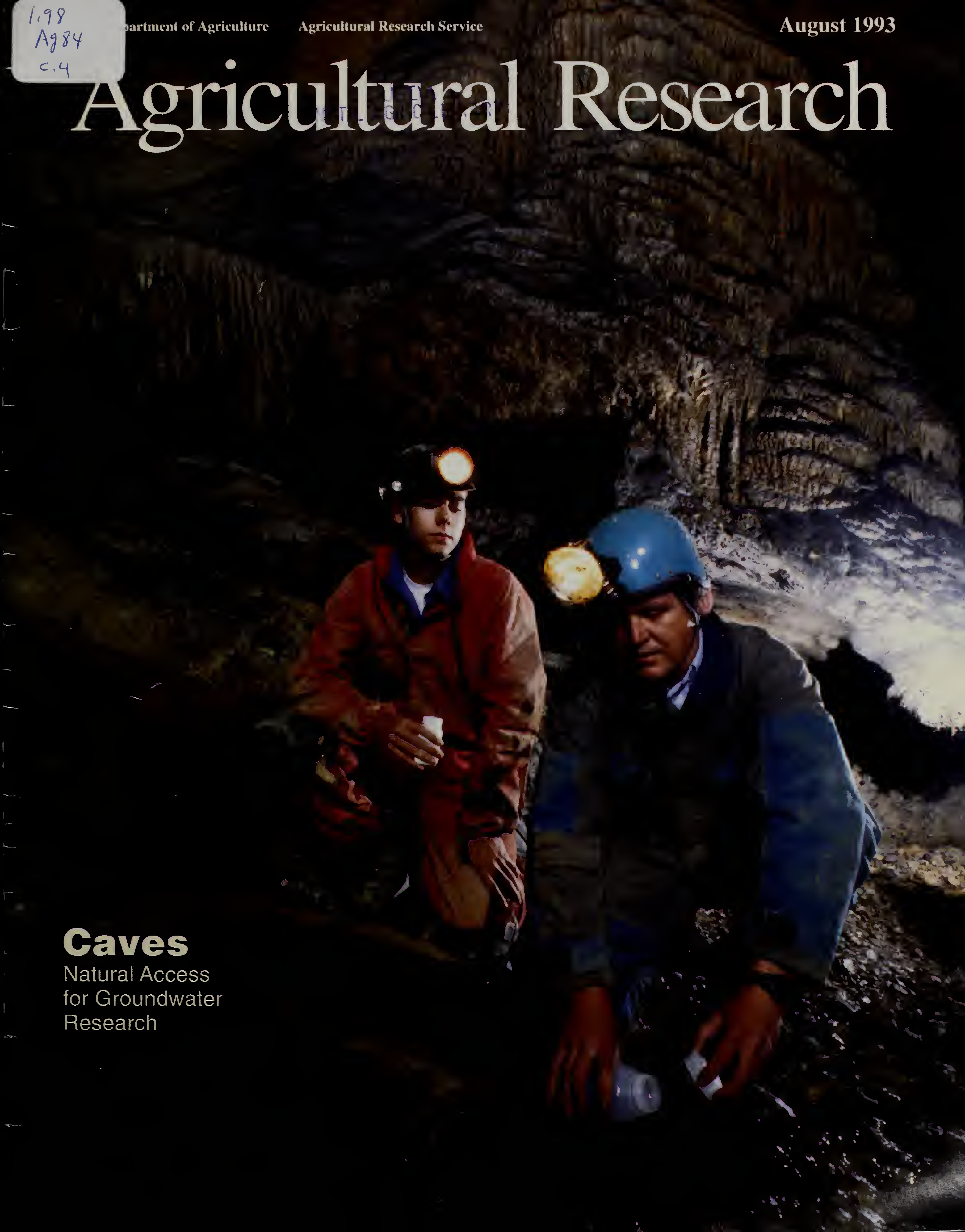

Caves

Natural Access for Groundwater Research

FORUM

The Rhizosphere—A Great Unknown

Try this some hot summer night: Walk barefooted into your backyard, feel the grass beneath your toes, and take a good, long look at the stars above you. Then consider this: Modern science, with all its high-tech gadgets and wizardry, knows more about the realm above your head than the few inches beneath your feet.

But, you protest, an expensive, complex spaceship is needed to explore the heavens, whereas all it takes to explore the earth is a shovel. Here's the catch: As soon as that shovel's edge pierces the soil surface, as soon as the first chunk of soil is upturned, the world beneath the grass becomes a world disrupted, altered as surely as if it had been bombed.

The big, still-unanswered question is: What goes on in the undisturbed regions below the grass—what scientists call the rhizosphere, the upper 6 to 24 inches of the Earth's crust?

We know one answer to that question is "a lot." While it may look fairly placid to the naked eye, the rhizosphere is a teeming universe.

It's a jungle down there, complete with plants such as algae and plant roots, creatures that eat the plants (nematodes and bacteria, for example), creatures that eat other creatures (fungi, insects, and rodents), and even "vultures" of a kind—insects, fungi, and bacteria—all living and working together.

Why can't we see all of this going on in its natural state? The answer is obvious: The soil that is home to these entities is generally dense and certainly not transparent, so it's difficult for light and other electromagnetic waves to pass through it and bring back the information we want.

Sure, you can dig up a chunk of soil and study it. But that's similar to plucking someone from, say, the Kalahari Desert and taking them to Manhattan to study how people live in the Kalahari Desert. Much gets lost in the transportation.

In the case of the transplanted soil, digging it up destroys soil structural characteristics; changes the relationships between soil organisms, soil chemicals, and soil particles; and changes the gases in the soil—more oxygen added (from the digging and "fluffing"), more carbon dioxide lost from its former hiding places in the soil.

Then there are the soil microorganisms. Some die from drying out as their home is exposed to the atmosphere; others suffer from exposure to light. All in all, digging is not a very efficient way to learn what's going on in the soil.

Fortunately, we do have tools more sophisticated than shovels for our exploration of the rhizosphere. One is a rhizotron—in simple terms, a deep trench with a plate of glass against one wall and a roof over the whole structure. This allows scientists to go down into the trench and watch through the glass as roots grow and the larger denizens of the rhizosphere go about their routines.

Another tool is the minirhizotron, a clear plastic tube in the soil, through which a mirror or tiny camera goes exploring. But again, light is needed to collect the images, the tube itself disrupts the underground environment, and the overall area observed is very small.

Then there's Computer Assisted Tomography scanning—a CAT scan, just like the medical profession uses, and other imaging techniques that offer a glimpse of the underground world, or at least small portions of it.

Do we really need to know that much about the rhizosphere, the comings and goings of soil microorganisms, the life cycle of herbivores and carnivores that, for the most part, we can't even see?

The answer is an emphatic "yes." Humans and animals alike eat plants, and other plants give us shelter (trees for lumber) and clothing (cotton, for example). The life support system for these life-supporting plants is their roots, and the circumstances of the rhizosphere have a dramatic impact on the development and life of these roots.

Too few of the right kind of microorganisms, and a soybean plant isn't going to thrive and put forth its full potential in beans. Too dense a soil layer, and a plant's roots can't push down for moisture to sustain it when the summer turns scorching.

Gases are another important component of the rhizosphere. For example, oxygen concentrations in water-saturated soil may fall below 2 percent. This low level of oxygen triggers a whole host of responses in a plant, including the production of the gaseous plant growth regulator, ethylene.

While plants typically produce this gas at very low levels during growth and development, higher concentrations can inhibit root growth. Usually ethylene isn't produced in large enough amounts to cause that sort of trouble—but it can happen when there's not enough oxygen in the soil.

Plant roots and the underground world they live in are so closely intertwined that the boundary between them can be hard to pinpoint. Just as scientists are struggling to learn more about the support system that makes our world possible—plant roots—we also need to learn more about the other mysteries beneath the grass. We can't afford to ignore this underground frontier.

Richard W. Zobel
U.S. Plant, Soil, and Nutrition Laboratory
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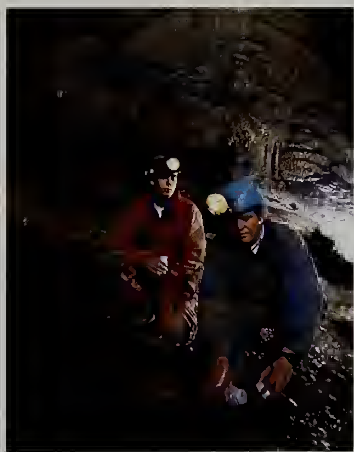
Agricultural Research



Cover: ARS hydrologist Doug Boyer (right) and aide Derek Hall collect water samples from a stream in a West Virginia limestone cave. The calcite formation in the background is The Haystack in McClung's Cave. Photo by Scott Bauer. (K5168-3)

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Scientists Go Underground To Check Water Quality

"The gate's shut and the stick trap is set," Derek Hall says. That's the signal for Doug Boyer to move on through the Hole of the Devil.

Boyer points to the jaw and legbones on the ground, the stark remains of a long-dead farm cow. Then he squeezes, winds, crawls, stoops, glides, jumps, splashes, plunges, soaks, wades, and slithers his way through the muddy, narrow passage called The Bathtub and Barefoot Creek.

The stick trap is placed strategically so it will be knocked down by anyone entering the cave behind Boyer and Hall. They don't want to lock the gate on the way out and accidentally seal any adventurer in The Hole's caverns.

Despite the challenge of negotiating the series of bathtublike holes along the tight, 400-foot-long entrance passage, The Hole has turned Boyer into a spelunker, or cave explorer. An Agricultural Research Service hydrologist in Beckley, West Virginia, Boyer has come to see caving as a way to get a worm's eye view of agricultural pollution. "Caves are Nature's drainage pipes," he says.

In fact, Bill Edwards—an ARS soil physicist in Ohio who studies earthworm tunnels as macropores that can funnel farm runoff downward toward groundwater—once accompanied Boyer on a caving expedition. He'd been intrigued by Boyer's boast that "we have macropores big enough to walk through."

Says Boyer, "Besides size, another difference between wormholes and caves is this: Caves descend hundreds of feet, to deep groundwater, while nightcrawler holes go down only a few feet. And sinkholes above the caves can act as giant funnels directing farm runoff water into caves. We're concerned because cave streams feed surface springs and wells used for drinking water."

Boyer is often accompanied by Hall, who works summers for ARS. He is an avid spelunker and a geology student at Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

When they make their serpentine journeys through The Hole, they are creeping under the 6-square-mile Hole Basin in Greenbrier County in southeastern West Virginia. The area's unstable topography is the result of underground water flowing through limestone bedrock and forming caverns, sinking streams, and sinkholes.

The sinkholes are ground-level depressions formed as surface water moves through fractures in limestone, often draining into underground

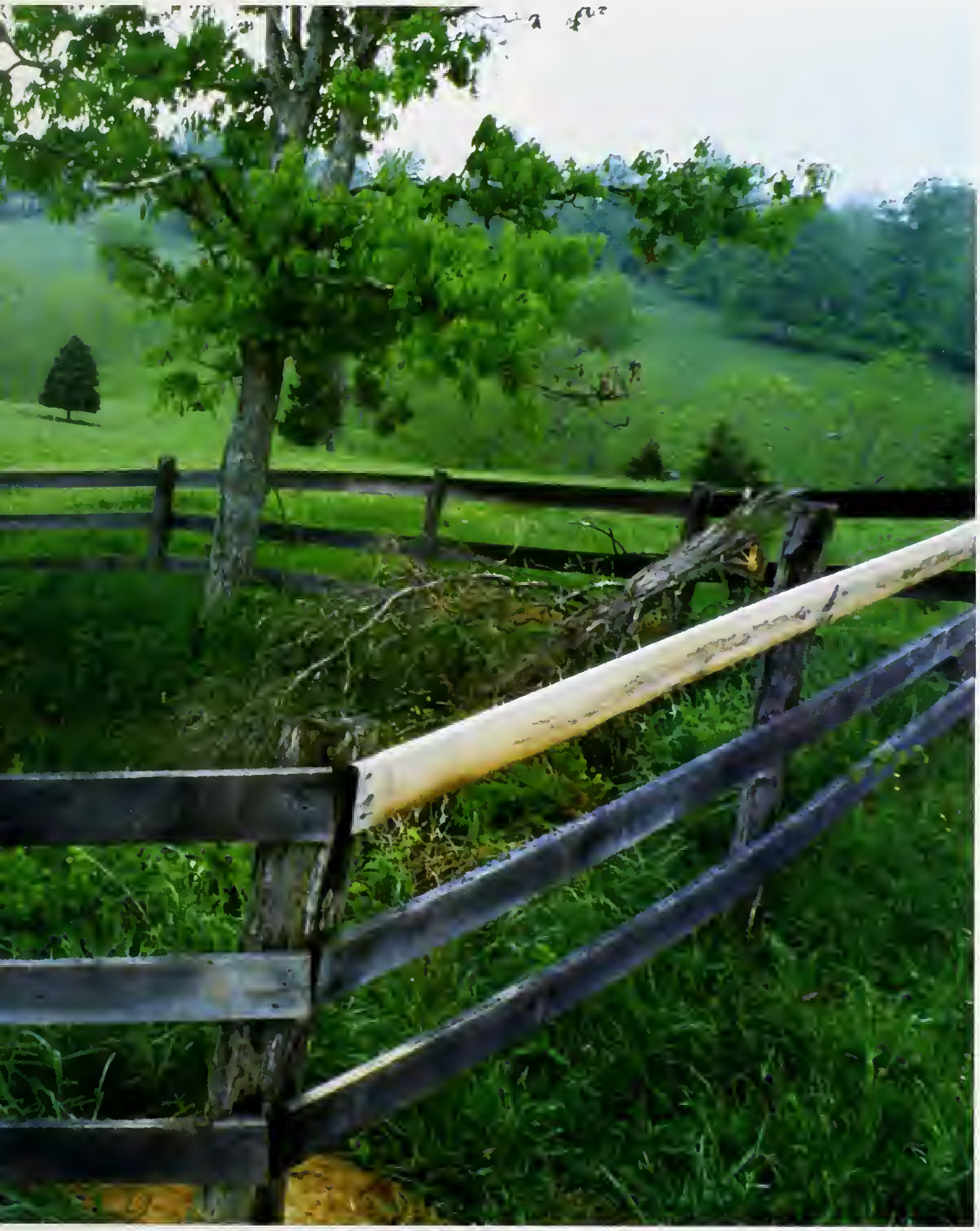
SCOTT BAUER

Hydrologist Doug Boyer and farmer Lloyd Burns visit a sinkhole on Burns' land near Lewisburg, West Virginia. (K5165-1)

passages. The water dissolves and breaks up the limestone as it goes along, eventually flushing away limestone pieces as it carves out underground passages.

Over time, the ground above collapses, forming surface depressions resembling potholes. Some view sinkholes as being like injection wells through which water, along with any chemicals that are either dissolved in water or attached to small particles, are channeled into groundwater.

The Hole is one of several drainage basins in West Virginia's Greenbrier River Valley watershed, which is one of 37 chosen in 1990 as demonstration sites for providing intensive educational and technical assistance to farmers. Each of the watersheds was chosen because the potential for agriculture-related problems to develop had been identified in state Clean Water Act reports to the U.S. Environmental Protection Agency.



The hydrologic unit demonstration and research project is part of a larger research and demonstration project under the Department of Agriculture's Water Quality Initiative. The initiative is designed to help farmers comply with state pollution management programs authorized by the federal Clean Water Act of 1987.

The project's purpose is to ensure that surface and underground water supplies are protected through safe use of fertilizers, manure, and pesticides.

"We want to understand waterflow in limestone so the USDA Soil Conservation Service can show farmers the best ways to protect underground water supplies," Boyer says.

As part of the water quality study, Boyer samples Greenbrier Valley springs at least weekly, with occasional samplings of the less accessible cave streams. He checks for nitrate from fertilizers and manure, as well as for herbicides.

Life Underground

Shade-seeking cows usually watch Boyer and Hall as they change into long underwear, extra layers of clothing, helmets, and overalls—despite sweltering summer heat. As the cavers descend toward the entrance, they are immediately refreshed by a flow of cool air from the cave, their breaths condensing from the cave air.

The entrance called Gibbs that Boyer unlocks this day is one of three used by the scientists to access this totally dark underworld illuminated only by odoriferous carbide gas lamps attached to the cavers' helmets.

Nothing can see in caves without these lights. Foxes and raccoons depend on a scent trail to enter and exit through both the human entrances and possibly smaller, unknown ones. Bats the size of very small mice come and go via tiny cracks hidden by pasture grass, navigating around cave curves and human cavers by bouncing sound waves off them.

Many creatures seek the cool of cave interiors during summer because, says Boyer, "Caves always stay at the average annual temperature of an area. In West Virginia, it's 54 degrees."

Armies of cave crickets enter and leave through their own secret passages, with two-thirds of their forces from each day's outing always remaining in the cave, for unknown reasons. Salamanders scurry blindly up cave ledges as mostly flatworms move about in the fishless underground streams. Sometimes an earthworm falls into a cave stream and survives to reproduce offspring with slightly different band markings probably caused by the absence of light.

A biologist Boyer once took to the stream was disappointed by the lack of diversity in stream life, a possible indicator of pollution.

Limestone Caves

The Hole is called a contact cave because it was formed by water steadily carving out the limestone down to where it met an insoluble layer of shale. The cave entrances formed where the shale layer surfaced and became a surface streambed.

Crawling over the crumbly and noisy shale pieces that line the creek beds, Boyer and Hall follow the shale steadily down, usually at a gradual 3- to 4-degree slope. Following Barefoot Creek's more abrupt drops and continuing on through aptly named formations like The Long Room, The Crossover, Adjacent Stream, Spike Street, Bullwinkle Boulevard, Broken Crockery Passage, and The Maze, they are soon hundreds of feet below the basements of farm houses and barns, cow pastures, and cornfields.

Bullwinkle Boulevard gets its name from a calcite formation that bears an uncanny resemblance to the cartoon character Bullwinkle Moose. Spike Street is marked by a spike made of gypsum crystal.

SCOTT BAUER

At Davis Spring, which is an exit point for underground cave streams in ARS' Greenbrier hydrologic demonstration project, technician Dale Baker tests water quality. (K5166-19)

Stalactites and stalagmites decorate the passages, sometimes flowing like stage curtains, other times meeting to form columns.

There are 38 farms above The Hole—two dozen that raise cows and calves, a dozen dairy farms, and two turkey farms.

The Hole has a bad reputation among cavers because of the 4-foot-high Bathtub passage and many miles of other small crawlways. It was named after Hölloch Cave in Switzerland, where *Hölloch* means hole of the devil.

The Hole consists of 23 mapped miles of labyrinthine passages carved by the Shale River and its tributaries as they wound their way down hundreds of feet below the surface. Some of the passages lie one above the other, at different levels. Over centuries, the water ate away much of the limestone layer at its point of contact with shale bedrock. At its deepest, the cave is under 750 feet of limestone. It is one of the longest caves in the world.

Bill Balfour, who has mapped much of The Hole and much of the 400 miles of other mapped caverns in Greenbrier, helped introduce Boyer to the county's caves. Balfour is a volunteer with the West Virginia Association for Cave Studies, which helps researchers like Boyer.

"We have accumulated data over 30 years and can save cave explorers the years of work it takes to compile information on caves or karstic areas," Balfour says. "We give them maps, suggest likely water sampling spots, and delineate drainage basins for them, so they're not going in blind."

He believes that Boyer's work is "very important because it provides good baseline information on water quality in limestone bedrock areas." He notes that "a tremendous amount of the country is underlain by limestone. A lot of good pasture, good rolling farmland, lies over this limestone and many people draw their drinking water from holes in the limestone bedrock."

Not many people pump water from limestone in The Hole Basin, Balfour says, but more do toward the west of the Basin, where the bedrock becomes thicker and it's harder to drill through to shale or sandstone.

Greenbrier County sits in the middle of the Appalachian Karst, a topography that results from the work of underground water on limestone bedrock,

Balfour says. Karst comes from the German *kras*, which refers to the bleak, rocky limestone found in coastal areas in the former Yugoslavia.

The major U.S. karstic areas occur in Kentucky, Indiana, Missouri, eastern Kansas, Oklahoma, northeast Iowa, Wisconsin, other parts of Appalachia, and Florida.

Even though the large, dramatic karstic topography is limited to these areas, there are caves in just about every state in the country, Balfour says.

The Karst Plateau in Appalachia is hardly stark, Boyer says. It is actually the most lush land to be found in that mountainous region of acid soils. The gentler limestone terrain and soil characteristics make it a more hospitable place for grass.

Native Americans learned this and expanded grasslands in the area for buffalo pasture by burning forests down, Boyer says. Now the area is called The Great Savannah.

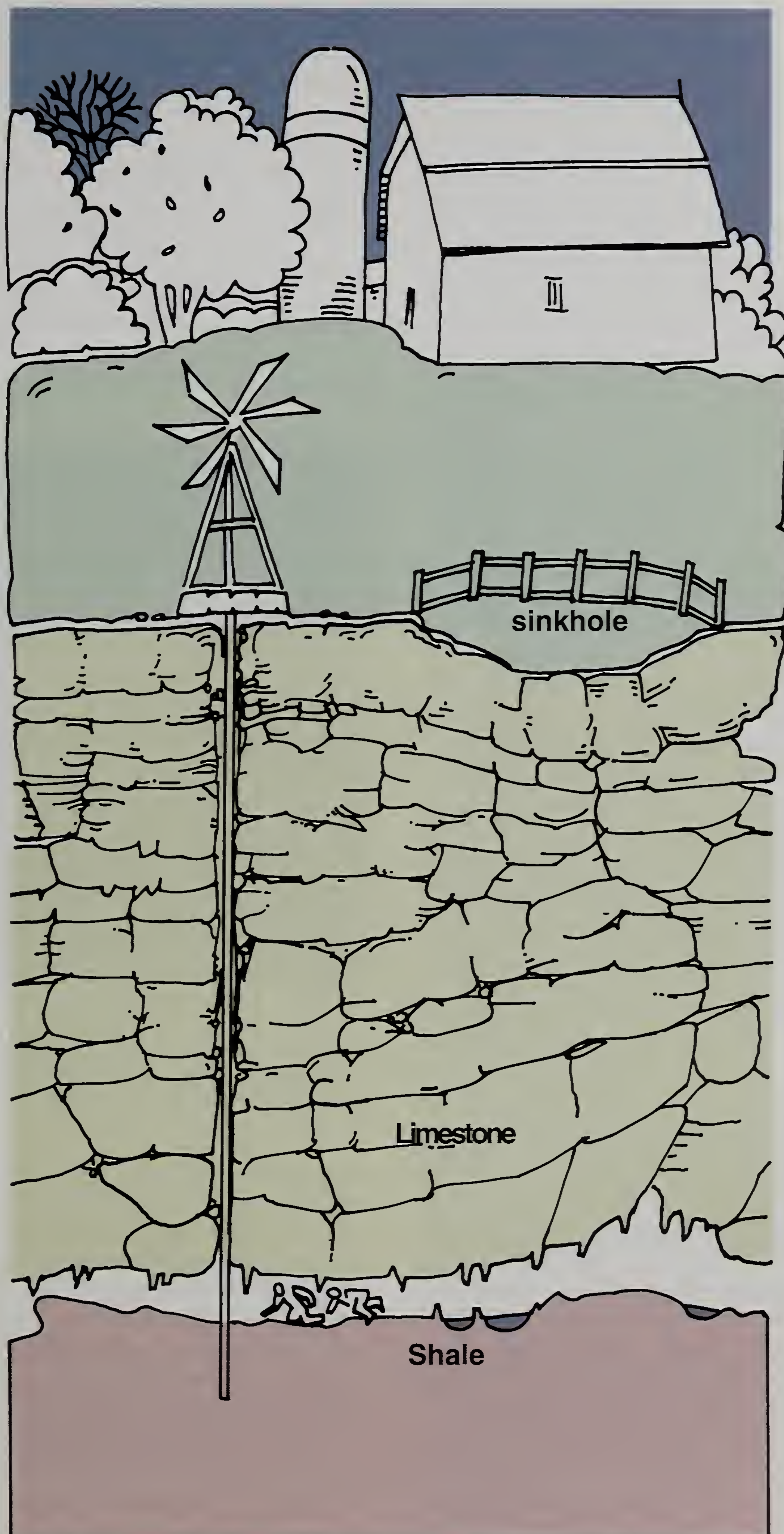
The Savannah grass makes it hard for the casual observer to distinguish sinkholes from river valleys.

What's Above Affects What's Below

In the Hole of the Devil, Boyer and Hall are deep under a farmstead. They stop to look at a section of the farm's well casing, a 6-inch metal tube inserted about 200 feet down for drinking water. When they return to the surface, they can see the windmill that pumps the water.

About 5 feet of the well casing's length is exposed momentarily in one of the passageways carved by Adjacent Stream. The well goes down below The Hole and draws from the shale layer beneath the cave floor. Once, they persuaded the farmer to join them on a 3-hour journey to the well and back.

The farmer's decision to draw water from beneath the cave was



wise, Boyer says. His samplings of cave water and springs for the past 2 years have convinced him not to drink the water. Besides nitrate, he samples for atrazine and related herbicides used to control weeds in cornfields.

He also samples for two kinds of fecal bacteria. When a high bacteria count coincides with a high nitrate measurement, Boyer believes the nitrate came from manure rather than commercial fertilizer or a natural source.

If Boyer has any doubts, after leaving the cave, he can drive his truck around the farm and see if there are cows above that part of The Hole.

While bats turn their upside-down heads slowly in his direction—trying, perhaps, to decide if it's time to wake up and fly away—Boyer uses a syringe to collect beads of water that decorate the cave ceiling like little pendant jewels under the artificial light.

He's invariably found high levels of nitrate in these drops. Boyer believes that natural soil bacteria in the cave are forming the nitrate by oxidizing ammonia when it enters the cave air. He plans to conduct experiments to check on this theory. Like nitrate, the ammonia can come from commercial fertilizer, manure, or natural sources.

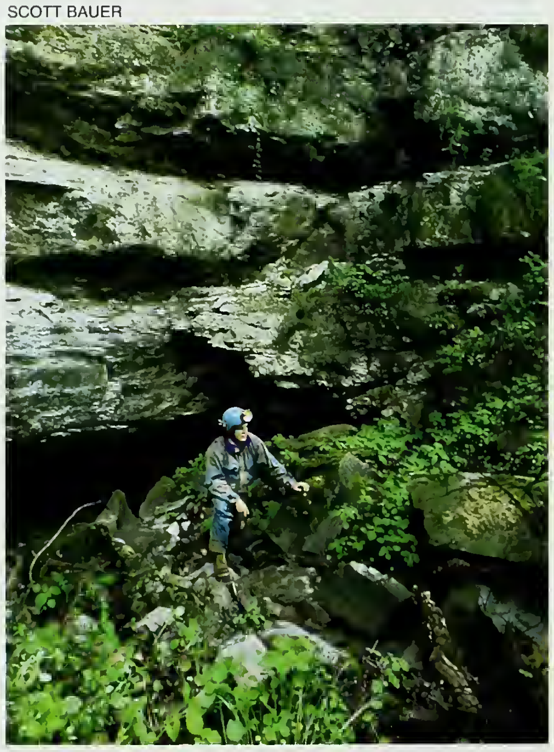
Boyer's journey today ended at The Maze, just below the sinkhole that feeds South Maze Stream, barely a half mile's journey. The one-way trip took about an hour and a half.

Boyer calls this part of South Maze Stream either Black Stream or Brown Stream, depending on how much biological ooze it contains on a particular day.

In it and its tributaries, Boyer has found average nitrate levels of 80 parts per million (ppm), accompanied by an excessive fecal coliform bacterial count of 10,000 colonies per hundred milliliters. U.S. Environmental Protection Agency guidelines for nitrate levels in drinking water call for a maximum of 45 ppm.

Boyer explains the reason for the drinking water guidelines: "Nitrate can cause blue baby syndrome in infants and can kill them at 300 ppm. When water is boiled as it is for infant formula, nitrate is left behind as water evaporates. With initial nitrate levels above 45 ppm, the boiled water could concentrate levels to 300 ppm or more. Also, nitrate—like nitrite which some people avoid

SCOTT BAUER



There are about a thousand caves in Greenbrier County. Here, hydrologist Doug Boyer emerges from The Hole after collecting water quality samples. (K5167-3)

eating because of health concerns—can convert to carcinogenic compounds, under certain conditions.

"You don't see levels anywhere near 80 ppm in the springs that emerge from these caves, because they are diluted by cleaner water before they emerge," Boyer says. "But we can sample the water under each different land use and discern the effects from that one land use." All he has to do is crawl around underground until he reaches the cavern directly below the suspect site.

Boyer explains that over the years, sinkholes have been seen as convenient dumping places by people unaware of their role as funnels to caves. State law forbids dumping objects but not agricultural waste into the sinkholes.

Lloyd Burns, a farmer who calls Boyer whenever he finds a hole in his fields, taught Boyer another reason farmers used to fill sinkholes. Burns has a 258-acre cattle farm in the rolling hills of Greenbrier County, above several other caves that Boyer has also sampled.

Burns told Boyer he grew up with the story of how one of his father's cows slipped through a sinkhole opening in the 1920's, falling 50 feet down. His parents often took him to the opening and told how his father, Sully, was lowered into the sinkhole by his neighbors and a team of horses. Sully tied the cow to a harness and had the team of horses pull the cow back up. Then his neighbors lowered a rope for Sully to escape as well.

The cow was unhurt, her fall cushioned by deep, thick mud at the bottom of the sinkhole. She survived to become pregnant and give birth to healthy twins.

Burns didn't realize he'd get to see his father in action again. When he was 6 years old, he went to feed some calves and noticed two missing. He knew where to check: Sure enough, Sully had to perform his legendary feat again, lowering himself by rope into the sinkhole and emerging with the help of horses.

That was the last straw for Sully. He filled the sinkhole with old fence wire and put a fence around it.

Boyer persuaded Burns to reopen the sinkhole so he and other cavers could explore it. Burns, Boyer, and several Boy Scouts removed enough debris to warrant a few trips to the landfill.

Boyer takes water samples on the Burns farm at least once a week; daily, after a heavy rain.

Burns says he is constantly on the lookout for agricultural pollution problems so he can do his part to stop a problem before it gets big. "I'm the last person to want pollution. I get my water from wells and would be totally helpless without it."

"I hope there won't be excessive regulations on agriculture— only needed ones," he adds. "I believe the truth about agricultural pollution is somewhere between what is said by extremists on both sides of the issue. Still, we can't continue to mess up the land, throw trash on it. I'm concerned about keeping the Greenbrier River pure and clean."

Tracing the Green Stream

Boyer is currently timing the flow of water through sinkholes by having colleagues flush hundreds of gallons of green-dyed water down each sinkhole. He has them wait 2 hours after he enters a cave, to give him time to reach the stream below the sinkhole.

When it rains hard enough to flush the dye down, Boyer checks to see how long it takes before the dye appears in a surface spring. He uses the dye, which is harmless, to confirm hydraulic connections, such as whether a particular sinkhole feeds a certain cave stream far beyond The Hole's South Maze Stream. He has traced waterflow through "bits and pieces of caves" to a spring on the Burns farm.

Boyer double-checks the dye connections by traveling through caves with a compass, measuring tape, and inclinometer to locate himself with respect to the surface by checking direction and angle of incline.

"We study waterflow through limestone because that's the route agrichemicals also take," Boyer says. "Pollutants can travel much faster and in different directions in caves, compared to other topographies."

While he doesn't see widespread agricultural problems so far, Boyer says it is important to monitor spring and cave water so nitrate doesn't get into groundwater.

Furthermore, "The accurate mapping of these underground drainage patterns will help the Soil Conservation Service work with farmers to develop farm management plans and practices that minimize the possibility of groundwater pollution."—By **Don Comis,** ARS.

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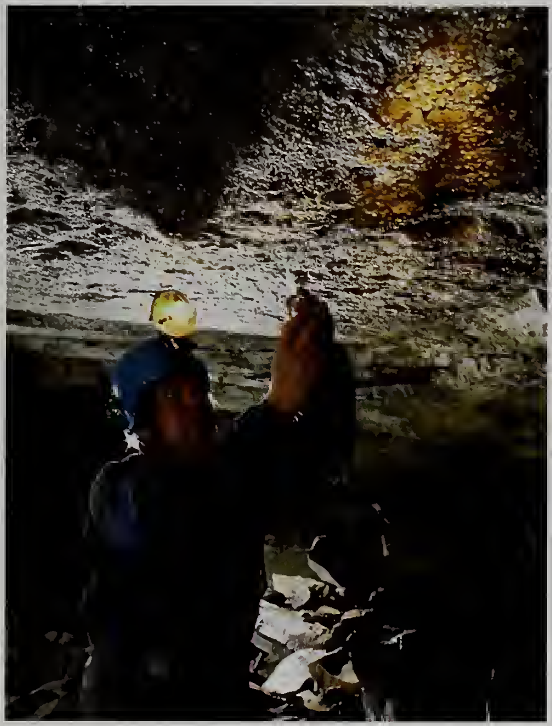
SCOTT BAUER



***Nitrobacter* bacteria are suspected of creating the high nitrate concentrations found in condensation droplets that hydrologist Doug Boyer is collecting near the entrance of The Hole cave. (K5164-2)**

Beckley: The Town With a Mine of Its Own

You can't spend even a day in Beckley, West Virginia, without getting an urge to go underground.

Fortunately, as the town's slogan implies, the town obligingly offers daily visits to an old coal mine.

About a half mile from Beckley's airport, the National Mine Health and Safety Academy nestles in mountainous woodland across the street from the ARS Appalachian Soil and Water Conservation Research Laboratory. The lab sits on 43 acres of similarly rugged terrain.

The academy addresses all mining safety-related activities throughout the United States. And although the ARS lab itself covers only the 121-million-acre Appalachian Region, it links to other ARS labs nationwide and is becoming an international authority on acid soils.

Even the academy's hotel and classroom buildings have a decidedly underground feel, with low lighting, exposed girders, and photos of mines.

The ARS lab opened in Beckley in 1980, to research reclamation of the acid soils of abandoned strip-mined areas. Its mission has expanded over the years to focus on farmland soils that are naturally acidic and infertile.

The lab has always had a water quality mission, beginning with studying the effects of runoff from abandoned mines. Now its role in USDA's Water Quality Initiative has brought it into the area of natural caverns as well. Fortunately, these "mines" are much more structurally stable than coal mines, because underground rivers like the Shale River have eroded all the weak layers and left mostly solid shale below and thick limestone above.—**Don Comis,** ARS.

GRENZWURZELN?

It's Just Another Word for Basal Roots

KEITH WELLER

Plant geneticist Richard Zobel examines corn roots suspended in an aeroponic chamber where mist provides both moisture and nutrients for growth. (K5169-5)

Many people know a German word or two that bring a smile: strudel, gesundheit, or maybe fahrvergnügen. For Rich Zobel, it's "grenzwurzeln."

That's the name—translated roughly as "boundary roots"—that a group of German scientists pinned on a specific type of plant root back in the mid-1800's.

But through the years, other scientists have discounted the existence of these roots as a separate type, contending they are simply a variation of the better known adventitious roots. But in the 1970's, Zobel not only began believing in grenzwurzeln—he grew them.

"The scientific literature has always indicated there were only three types of plant roots," says Zobel, a plant geneticist with the Agricultural Research Service at Ithaca, New York.

"There were the tap root, the first to emerge in germination; the lateral roots that do the real exploring in the soil; and adventitious roots that initiate from the stem and keep the plant standing up."

Zobel first recognized grenzwurzeln in the early 1970's while working with mutant tomato plants.

"A mutant is caused by one or more genes doing something different," he explains. "It turns out that tomatoes have quite a few genes that don't have lots of copies in the chromosome. So in a tomato plant, a gene that's making the difference is easier to find.

"I thought that if I could find certain crucial genes in tomatoes first I could then look for those same genes in other crops such as corn."

When Zobel crossed a mutant tomato plant that had no lateral roots with one that had no adventitious roots, he should have gotten an offspring with only a tap root, according to the conventional wisdom that said only those three types of roots existed.

Instead, the crossbred offspring had a tap root, plus half a dozen other large roots sprouting from the plant's base. These Zobel dubbed "basal roots," in reference to their point of origin on the plant, but he says they're the same as the Germans' grenzwurzeln.

Two years later, Zobel discovered another believer in grenzwurzeln—a scientist named Lenore Weinhold.

"She had published a paper in 1966 that showed basal roots existed in monocotyledonous plants such as wheat and corn, as well as in dicotyledonous plants like tomatoes and soybeans," says Zobel. "But nobody really paid attention, just as they'd ignored the earlier scientists."

Zobel isn't particularly surprised by the confusion about how many types of roots exist. In fact, he says the entire science of roots is as tangled as an uprooted corn plant, starting with the names of the various roots.

"Just look at the tap root," he says. "The name "tap root" refers to the tendency of the first root to emerge from the germinating seedling and grow directly downward, "tapping" the soil. But it's also called both the radicle and the primary root, because it's the first one and the main root for supporting seedling growth and development.

"Frequently, additional roots develop in the plant embryo and emerge soon after the tap root. These roots are called seminal roots in grasses, but they're also called laterals, adventitious roots, primary laterals, and primary adventitious roots."

Until Zobel's and Weinhold's work, the seminal roots of grasses were thought to be some sort of variation of an adventitious root, rather than a separate type.

Looking beyond and complicating the question of identity, Zobel points out that roots' roles can change with time.

"When a plant is very young and all it has is its tap root, that's the root taking up water and nutrients to nourish the plant," he notes. "But when the basal roots form, the tap root generally stops taking up nutrients. Then, when the laterals arrive, they take over from the basal roots.

KEITH WELLER

The white root extending toward the lower right corner is a fourth type known as a basal, or seminal, root. (K5169-19)

"The laterals are the ones that finally do the really important exploring and absorbing," he continues. "The tap root, basal, and adventitious roots simply provide the central plumbing through which nutrients and water move in the plant."

In direct contrast to the common conception of the tap root, that particular root is not especially efficient at taking up either water or nutrients, Zobel says.

"But it doesn't have to be," he adds. "It's really involved in nutrient and water uptake only in the very early stages of the plant's growth, and at that time the plant seedling is so small it doesn't need very much."

Instead, as plants grow, it is often the basal roots that probe ever deeper into the soil in search of more water.

"A real difference between monocots and dicots is the ability of the roots to get larger and increase the volume of water they can carry as a plant gets older," says Zobel.

"In monocot plants, the roots don't do that; they just put out new and larger adventitious roots. But the basal roots in a dicot grow thicker and thicker, to allow more water to be taken out of the soil."

Zobel says all plants have the potential to produce all four root types: tap, lateral, adventitious, and basal.

"However, at any given time you may not find all four on a specific plant," he adds. "Many dicots don't show adventitious roots all the time.

New Roots to the Rescue!

"Occasionally, when they're under extreme stress, such as drought, a dicot will grow adventitious roots. If, for example, you deliberately kill a dicot's basal roots and tap root, you can usually get that plant to grow adventitious roots."

This ability of plants to respond quickly to stress with a new array of roots has been demonstrated in Zobel's experiments at ARS' U.S. Plant, Soil, and Nutrition Laboratory at Ithaca.

"We use a system called aeroponics where you hang plant roots in a fog," he explains. "By changing the density of the fog, you can make the plants 'think' they're in a drought and then relieve the 'drought' and see what happens. We've done this with corn, tomatoes, and soybeans.

"In our soybean work, we reduced the amount of water in the fog for about 2 days and then increased it.

Within 12 to 24 hours, the soybean plants grew new adventitious roots a couple of inches long, to get every bit of water available. This is the first time this has been seen under artificial conditions."

Lateral roots, responsible for acquiring the lion's share of water and nutrients from the soil, are simply branches sprouting from other roots, Zobel notes.

"In soybeans, if the top layer of soil dries out, the laterals are so small that they dry up, too," he says. "But the basal roots don't; they're the emergency back-up system. Then when the soil is wet again, the plant puts out new laterals from the basal roots."

Plant roots are strongly affected by the environment in other ways as well. For example, if carbon dioxide concentrations are higher than 0.5 to 2 percent in the soil's "plow layer," the CO_2 stimulates the plant's roots to grow outward rather than downward, leaving a vacant region directly beneath the plant, Zobel says.

"The final form of a root system depends as much on the environment in the soil as it does on root types," he notes. "Temperature, gases, soil structure, soil chemistry, and microorganisms in the soil all control the rate and pattern of root development.

"For example, how deep roots will go into the soil can be greatly modified by soil physical conditions, such as compaction or presence of a soil pan—a layer of dense soil below the surface that's too difficult for the roots to penetrate. This can make rooting patterns differ across a single field."

Nutrient Uptake Secrets

Zobel and ARS plant physiologist Leon V. Kochian have been studying the ways in which plant roots take up soil elements such as potassium and nitrate.

Kochian has already shown that when soils contain excessive aluminum, a major obstacle to crop growth, the harmful effect of the aluminum on the plant hinges on whether aluminum comes in contact with the root tip or elsewhere on the plant root. [See "Understanding Aluminum Toxicity in Plants," *Agricultural Research,* November 1992, p. 23.]

KEITH WELLER

Plant geneticist Richard Zobel checks the root systems of stressed corn plants to determine the impact on root growth and development. (K5170-9)

In studies at the Ithaca lab, Zobel, Kochian, and research assistant T.G. Toulemonde used microelectrodes to check tomato plant roots' ability to take up potassium and nitrate.

They found that uptake rates of potassium were similar for 7-day-old tap roots and 7-day-old basal roots at a point 4 centimeters from the tip.

But at the root tip itself, the basal roots took up significantly more potassium than did the tap roots, Zobel says.

"Nitrate uptake was different, though," Zobel notes. "As far as 2 centimeters from the root tip, nitrate uptake by tap roots increased fairly steadily in plants that were 1 and 2 weeks old. But at 3 weeks and older, the tap root's nitrate uptake dropped off dramatically rather than remaining constant with distance as was widely believed."

Basal roots showed a similar pattern of nitrate uptake, but at much lower levels, he adds.

"For the last 150 years, scientists have thought they knew what a root is, how and why it develops, what it does, and how and why it does it," Zobel says. "It's becoming increasingly apparent that for most plant species and growing conditions—including greenhouse conditions and hydroponics—we don't know the answers to these questions after all.

"There are very practical applications for this information. For example, maybe we could develop a soybean plant with an especially strong tap root. In the Southeast, there are compacted areas of the soil where roots can't penetrate. A soybean with a stronger tap root could push on down to where the water may be.

"I suspect that if we keep studying roots, we can someday manipulate them for improved crop growth."—By **Sandy Miller Hays**, ARS.

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Subterranean Fixation

Roots' Role in the Soil Nitrogen Cycle

For years, farmers have known the benefits of planting corn after alfalfa and soybeans. These two leguminous crops are well known for their ability to supply nitrogen from the air for their own growth and to enhance soil fertility for succeeding crops.

Now, an ARS soil scientist in St. Paul, Minnesota, is getting to the bottom of how alfalfa transfers nitrogen to the soil by viewing the underground death and decay of roots.

"Most knowledge of how roots affect plant growth and health has been inferred by studying plants above ground," says Michael P. Russelle of the ARS Plant Science Research Unit. "However, to really understand nutrient uptake and cycling by plants, we need to know more about root growth and death."

An acre of alfalfa is laced with about 13,000 miles of roots in the top 6 inches of soil and many more thousands below that. The development of small video cameras has enabled Russelle and University of Minnesota agronomist Markus Dubach to observe these root mazes through clear plastic tubes buried in the soil.

In the summer of 1991, they took a miniaturized video camera into the field and monitored how many alfalfa roots died during a growing season. Analysis of time-lapse sequences of those videos shows that 64 percent of the fine roots at 4 inches and 50 percent of the fine roots at 8 inches decomposed as the alfalfa grew.

"Plants lose small roots during growth, just like they lose leaves, and then replace them with new ones," says Russelle. Decomposing roots are a source of nitrogen that can contribute to a more fertile soil. The challenge for Russelle and Dubach is to find out how much nitrogen is contributed by dead alfalfa roots.

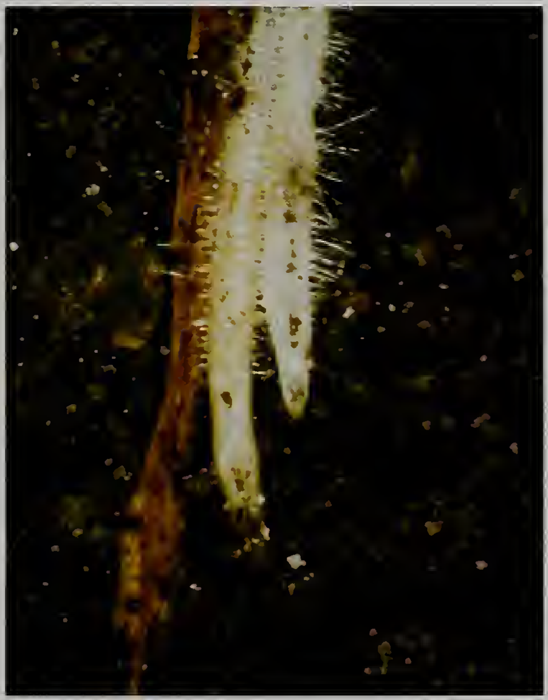
But two major problems have stood in their way. The first was that no one knew how much nitrogen these fine roots contained.

So Russelle and Dubach grew alfalfa in root observation boxes to learn the age and condition of many roots. Later, they surgically removed the roots from the soil and measured their nitrogen content.

They calculated that if 2,000 miles of fine roots decomposed, about 1 pound of nitrogen from the air would be transferred to the soil.

The next problem was that no one knew the lifespan of fine alfalfa roots. These fine roots—often less than one sixty-fourth of an inch in diameter—could be seen with the miniaturized camera. The camera magnifies a section of soil one-half by two-thirds of an inch in size and projects an image on a television monitor. In the upper 8 inches of soil, these fine roots have a lifespan of less than 2 months during the summer.

MARKUS DUBACH



Alfalfa plants lose small roots during growth, just like they lose leaves, and then replace them with new ones. Decomposing root (left) contributes nitrogen to the soil. (K5087-1)

The story of fine roots dying and decaying in a field is just the small picture. The big picture involves nitrogen recycling throughout croplands in the Corn Belt.

The nitrogen cycle goes like this: Alfalfa is planted as a forage for animals. While the alfalfa grows, bacteria living in nodules on the roots capture nitrogen from the air. The soil inherits the valuable nitrogen left behind as roots die and after the alfalfa stand is plowed under in preparation for the next crop.

After harvest, the alfalfa is fed to animals as hay or silage. While some of the nitrogen is converted to meat and milk, most—about 70 percent—is excreted as manure. Most of the manure nitrogen can be returned to the soil, thereby completing the nitrogen cycle.

Alfalfa—the most popular dairy forage in the United States—is grown on 26 million acres. More than 10 million acres are grown in the eight states of the eastern part of the Corn Belt—Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin.

"This alfalfa acreage adds more than 1 million tons of nitrogen to farms in the region every year through nitrogen fixation," says Russelle. Russelle and Todd A. Peterson, an ARS research associate, have studied alfalfa's impact on the regional nitrogen cycle.

On the average, farmers here could cut fertilizer nitrogen use by 14 percent, without reducing corn yields, and save about $100 million a year.

"It's important for farmers to recognize this nitrogen source and avoid over-application of fertilizer nitrogen," says Russelle. "By including alfalfa as part of their cropping system, they get a valuable crop and free nitrogen besides."—By **Linda Cooke,** ARS.

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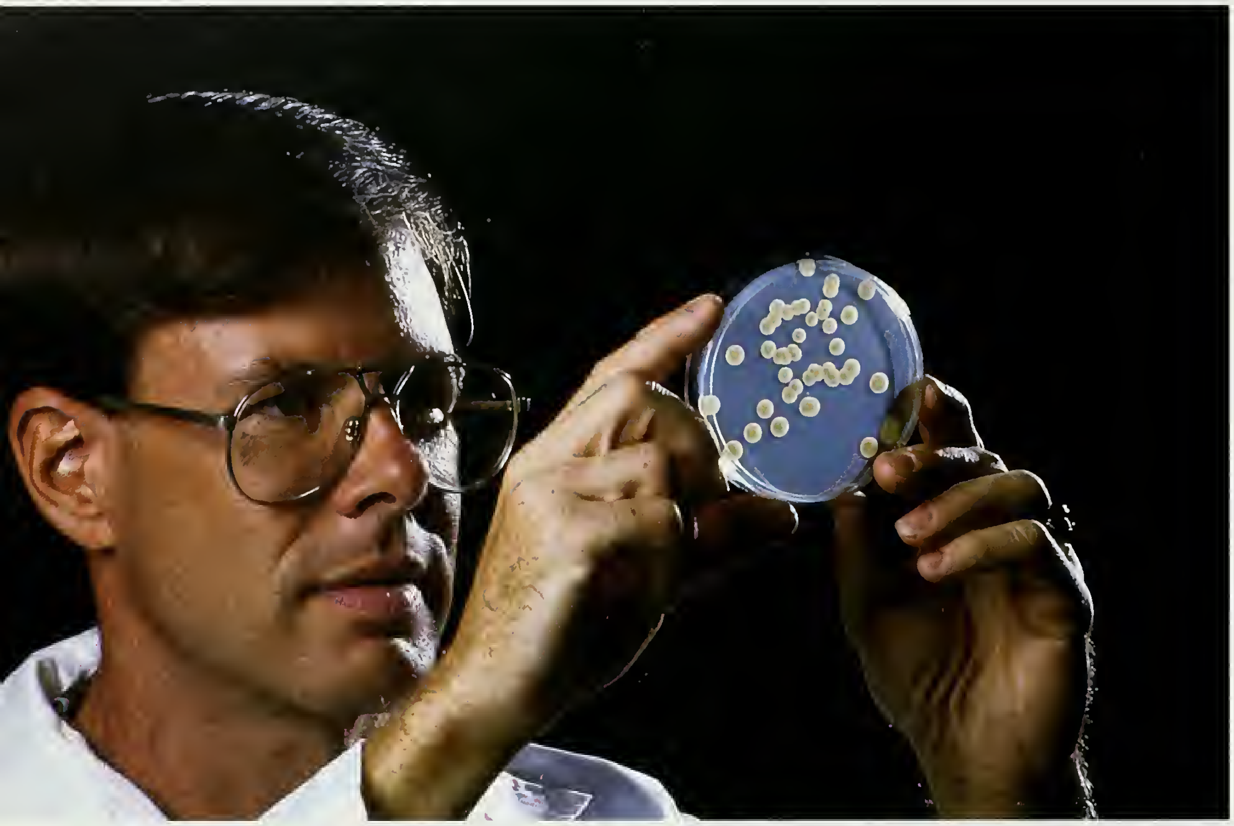
SCOTT BAUER



Plant pathologist Ray McGuire examines cultures of *Candida guilliermondii* yeast to be used on stored grapefruit to prevent green mold. (K5162-6)

Fighting Fruit Decay Nature's Way

Ah! Juicy, tart-sweet grapefruit—perfect at breakfast or at any other time of the day.

But grapefruit, like many other tasty fruits, is not without its problems. And sometimes the solution to one problem is the cause of another.

For example, federal regulations require Florida citrus shippers to certify that fruit is free of fruit flies that could perhaps hitchhike a ride to other citrus areas and damage crops. But some of the special treatments devised to protect citrus produced in fruit-fly-infested areas leave the fruit more vulnerable to disease-causing microbes. [See box.]

One new treatment that is very effective against fruit flies—heat—kills 99 percent of all microorganisms, including beneficial ones, present on fruit surfaces. But during storage, heat-treated fruit can become reinoculated with pathogenic microorganisms, which then multiply, unhindered by competition from any beneficial ones.

Now, Raymond G. McGuire, a plant pathologist at the ARS Subtropical Horticulture Research Station in Miami, Florida, has found that adding a natural yeast, *Candida guilliermondii*, to fruit coatings fights mold organisms and extends shelf life for up to 2 months. Most citrus is waxed at the packinghouse to prevent moisture loss during shipment and storage.

Grapefruit are vulnerable to a species of *Penicillium* that causes green mold to cover the surface of the fruit. This mold thrives on nutrients taken

Treating for Fruit Flies

Plant pathologist Raymond G. McGuire says that because the Caribbean fruit fly, *Anastrepha suspensa*, is a pest of Florida grapefruit, consumers in Arizona, California, Hawaii, Texas, and Japan could have a real problem getting the fruit.

Since these and other citrus-growing areas don't want to import the caribfly, citrus shipments from fly-infested zones in Florida must be treated to ensure the fruit is fly-free before its entry is allowed. Cold storage and methyl bromide fumigation are currently approved quarantine treatments that kill immature fruit flies in grapefruit.

"But both of these methods have drawbacks, including costs and possible environmental hazards" explains McGuire. "That's why ARS scientists have been experimenting for several years with new treatments using hot water, vapor heat, and forced hot air."

Fast and effective for controlling fruit flies, these new methods are being investigated as quarantine treatments. But heat treatments also create a problem because they may make fruit more susceptible to decay during storage.

Adding a beneficial yeast to fruit coating applied at the packinghouse may be an answer to this problem.

SCOTT BAUER

Healthy grapefruit (left) was coated with wax containing the biological control yeast. An untreated fruit stored the same length of time has decayed. (K5159-19)

from the fruit's surface. But the yeast used by McGuire apparently steals these nutrients and uses them to multiply more quickly than the mold. And the coating in which the yeast is mixed may also provide useful nutrients for its growth.

The yeast survives well over periods of adversity. This, plus its ability to use the large variety of carbohydrates and organic acids available on the surface of grapefruit, make the yeast an ideal candidate for biocontrol of the mold, McGuire says. It is not noticeable on treated fruit.

According to McGuire, antagonists have been tested on fruit surfaces by artificially placing massive numbers of organisms directly on wounded areas of fruit. But this would not be very practical in reality. "To be commercially acceptable, application of a biocontrol agent must be compatible with packinghouse operations," he says.

Since packinghouses already wax citrus fruit, this is the ideal time to apply a biocontrol agent. The wax, or coating, would not only bind the yeast to the fruit, but could also be formulated to promote its growth on the fruit surface.

To study the feasibility of using the yeast commercially in a fruit coating, McGuire is working with Craig Campbell, director of research and development for J.R. Brooks and Son, located in Homestead, Florida. This company, one of the largest shippers of tropical fruits and vegetables in the United States, is back in full swing after being hard hit by Hurricane Andrew last year.—**By Doris Stanley**, ARS.

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Protective Yeast Is Patented

Discovered on lemons and patented by Charles L. Wilson, ARS plant pathologist at Kearneysville, West Virginia, *Candida guilliermondii* is is pending approval by the U.S. Environmental Protection Agency and is licensed for commercial production by Ecogen, Inc., of Langhorne, Pennsylvania.

The fruit coating that Raymond G. McGuire is using in his research was developed and patented by another ARS scientist, Myrna Nisperos-Carriedo, a chemist at Winter Haven, Florida. Called Nature Seal, the coating is now commercially produced by Seald-Sweet Growers, Inc., in Vero Beach, Florida.

SCOTT BAUER

Grapefruit emerging from a commercial packing line washer undergoes inspection by plant pathologist Ray McGuire (left) and technician Everton Bahter. (K5158-12)

SCOTT BAUER

After washing, fruit receives a spray of wax and a yeast that biologically prevents mold development. (K5163-8)

Sugarbeets

Controlling Pests in the Next Century

George Washington loved to experiment in his garden and fields at Mount Vernon. Some of the crops that struck him as novel and innovative in the 1790's are standard today on the American agricultural scene—alfalfa, for example, and cultivated pecans. Others, such as the forage legume called sainfoin, are still seeking a toehold in U.S. agriculture.

One current crop that would have been new to Washington's America is the sugarbeet, from which crystalline sugar is made. Introduced in the late 1700's, sugarbeets gradually gained acceptance until they now provide slightly over half of the sugar produced in this country.

In the 1930's, their rising significance caused U.S. Department of Agriculture plant geneticist George H. Coons to go plant exploring. During his travels through seven European countries, he looked for sugarbeets and their wild relatives that might resist a costly leaf spot disease caused by the fungus *Cercospora beticola.*

BRUCE FRITZ

Plant geneticist Garry Smith examines a sugarbeet root maggot parasitized by beneficial *Steinernema* nematodes. (K5175-1)

Coons' scientific harvest was, unfortunately, a lean one.

After carefully crossbreeding wild plants and cultivated sugarbeet varieties, he found little or no resistance in the hybrid offspring. Afterward, he wrote with regret that his "tests were given up, probably too soon." In this, he turned out to be right. Years later, colleagues found the resistance he had searched for in the materials he'd gathered.

William M. Bugbee, a plant pathologist with USDA's Agricultural Research Service, took the fight against sugarbeet diseases a few steps closer to victory when he isolated and identified certain bacteria from inside and around the roots of sugarbeets in the early 1970's. These bacteria did not cause disease, Bugbee noted.

But it wasn't until the late 1980's that ARS scientists at Fargo, North Dakota, began to consider a use for these seemingly meaningless bacteria—specifically, to serve as workhorses for biological control of sugarbeet pests.

The pest at the top of plant geneticist Garry A. Smith's "most wanted" list was the sugarbeet root maggot, which was emerging as a serious problem in North Dakota and Minnesota farms of the Red River Valley.

The maggot had shown itself capable of reducing yields by 10 to 50 percent by feeding on the surface of tap and lateral roots. The larvae consume a mixture of plant juices and bacteria and form slime tunnels along the roots.

But chemical insecticides seemed only a short-term solution, Smith noted, since soil was sometimes too dry for the insecticides to work well and they appeared to be losing their effectiveness.

So, with partial funding from the Beet Sugar Development Foundation and increased federal funding, the Fargo lab embarked on a renewed search for natural weapons against the sugarbeet root maggot.

Smith envisioned genetically engineering Bugbee's ubiquitous bacteria to produce a fatal *Bacillus thuringiensis* (Bt) toxin and then lying in wait for the voracious sugarbeet root maggot.

Derived from a common bacterium and used against crop pests for more than 30 years, Bt toxin is harmless to humans and livestock.

Smith says that another biocontrol route—genetically engineering a sugarbeet variety to repel or resist the pest—would take more time, which the sugarbeet industry could ill afford.

Alternative Biological Strategies

"In our long-range view, we embrace the idea of genetically engineering sugarbeet plants to resist pests," Smith says.

One method that might help with this strategy is if a strain of *Agrobacterium tumefaciens* can be found that infects sugarbeets. The idea is to use the microbe to ferry DNA material from Bt into the hereditary makeup of the sugarbeet plant. So far, molecular biologist Chris A. Wozniak has discovered several natural strains in the soil near sugarbeets, but none that actually infect sugarbeets.

The Fargo scientists are trying to identify the Bt strains that produce the most potent toxins against the maggot, with the hope of applying the bacterium directly to plants without first engineering the toxin gene. This would allow them to pit Bt directly against the maggots.

If that doesn't work, perhaps a bacterium such as *Xanthomonas*

maltophilia (*Xm*) from the sugarbeet's microbe-rich ecosystem could be redesigned to make Bt toxin.

Wozniak and ARS plant physiologist John D. Eide have identified about 500 bacteria from among 2,000 bacteria samples collected from the sugarbeet root maggot's midgut and slime tunnels and from the surface of sugarbeet roots.

Among biological samples from the maggot-infested cropland in Minnesota, North Dakota, Montana, Wyoming, and Nebraska, the researchers found *Xm* everywhere, making the bacterium a likely candidate for their genetic engineering work.

The ubiquity of *Xm* makes the scientists suspect the microbe might be needed for the maggot to thrive. Indeed, after rearing some germ-free maggots from disinfected eggs, the researchers found none capable of larval development unless *Xm* was added to their diet.

By genetically engineering *Xm* to make Bt toxin, "we hope to create a situation in which the sugarbeet root maggot can't live with the microbe and can't live without it," says Wozniak.

Serendipitous Nematode Study

It came about in the fall of 1992, when Smith and ARS plant pathologist David T. Kaplan of Orlando, Florida, found themselves at the same location on temporary assignments.

As they sat at dinner one evening, they talked about the work they did back home. Their discussion led to a question: Could a microscopic nematode known to Kaplan that had shown promise against a citrus pest also be put to work in northern sugarbeet fields?

The prospect was appealing because the nematodes in question, from the genus *Steinernema*, kill only insects, leaving plants and warm-blooded animals untouched.

Steinernema nematodes are like a "gift that keeps on giving," says Wozniak. They enter natural openings in their host, then release bacteria from their intestines that get into the maggot's blood and produce deadly toxic waste products.

These bacteria multiply in the maggot cadavers and serve as food to nourish the nematodes as they prepare to reproduce. If a nematode harbors a potent species of these bacteria, it typically produces thousands of offspring.

Smith, Kaplan, and their colleagues set up laboratory studies at Orlando and obtained permits to allow interstate transport of the insects and nematodes and to conduct field studies at Fargo. The U.S. Environmental Protection Agency had earlier determined that *Steiner-*

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Slightly over half of U.S.-produced sugar comes from sugarbeets.

BRUCE FRITZ

Technician Gary Nielsen (foreground) and plant pathologist William Bugbee collect axillary buds from *Rhizoctonia*-resistant plants with high levels of a protein that inhibits cell destruction by the enzyme pectin lyase. (K5174-1)

nema nematodes, with their associated bacteria, are exempt from registration requirements under the Federal Insecticide, Fungicide, and Rodenticide Act.

In preliminary North Dakota field tests, all of six *Steinernema* strains—representing the *carpocapsae*, *feltiae*, and *glaseri* species—proved capable of entering the sugarbeet root maggot and reproducing as their hosts are about to pupate.

Besides learning that sugarbeet root maggots are infected in the larval stage by *Steinernema*, researchers have discovered that the adult or fly stage can be infected within 2 hours by these nematodes and die within a day. This year, they are testing fly traps baited with an attractant containing nematodes, to determine the rate of adult infection in the field.

But researchers aren't yet certain how well the nematodes suppress the maggots. Even in plots without the beneficial nematodes, sugarbeets grew too well to visibly suffer much maggot damage.

So the studies have been refined to include more field sites and nematode applications at different stages of crop growth.

"Our outlook for success is good," Smith says. "Although nematodes may not become the complete answer, they could help fill a big control gap if available insecticides should ever be taken off the market."

Also, the nematodes might be relatively inexpensive—perhaps less than 10 cents per million, or about $30 for enough to treat an acre. A large ethanol-producing company is licensed to rear them in fermentation tanks. They are being marketed through garden supply firms.

"We don't know yet whether farmers would need to apply nematodes each year, or if sufficient numbers of infective juveniles would overwinter," Smith says.

DEVON DONEY

USDA plant explorers find potentially valuable germplasm in many locations, such as these wild beets growing in Brittany, France.

Breeding in Plant Resistance

Can the sugarbeet root maggot problem also be curtailed by breeding beets with insect resistance? In research plots near St. Thomas, North Dakota, that are normally heavily infested, ARS plant geneticist Larry G. Campbell has developed breeding plant populations with resistance comparable to that achieved in plots treated with chemical insecticides.

But because the beets lack yield potential and other desired qualities, and because genes affecting resistance may be widely dispersed in the plants' chromosomes, Campbell says resistant sugarbeets won't soon be commercially developed.

Campbell is evaluating sugarbeet root maggot resistance in 17 wild sugarbeets initially screened by entomologist Albin "Andy" W. Anderson of North Dakota State University from about 190 accessions obtained from the USDA-ARS Plant Introduction Station in Ames, Iowa.

Other conventional breeding work to develop beets resistant to *Cercospora* leaf spot is under way, says Smith, including some that plant explorer Coons had collected.

Cercospora now infects about half of all U.S. sugarbeet acreage, causing millions of dollars worth of losses each year.

Recently, Smith and Eide found high levels of the enzyme chitinase in sugarbeets that have a natural ability to withstand *Cercospora*. They are now preparing antibodies to chitinase that researchers may use in screening sugarbeet seedlings for resistance with a test known as ELISA (enzyme-linked immunosorbent assay).

It is expected that an ELISA test will greatly speed up the search for resistant sugarbeets.

Often, the value of genetic resources may not be recognized until decades after they are collected, says ARS plant geneticist Devon L. Doney. He has helped plan the Third Biennial Conference of the World Beta Network, an international forum of sugarbeet geneticists set for August 4-6, 1993, in Fargo.

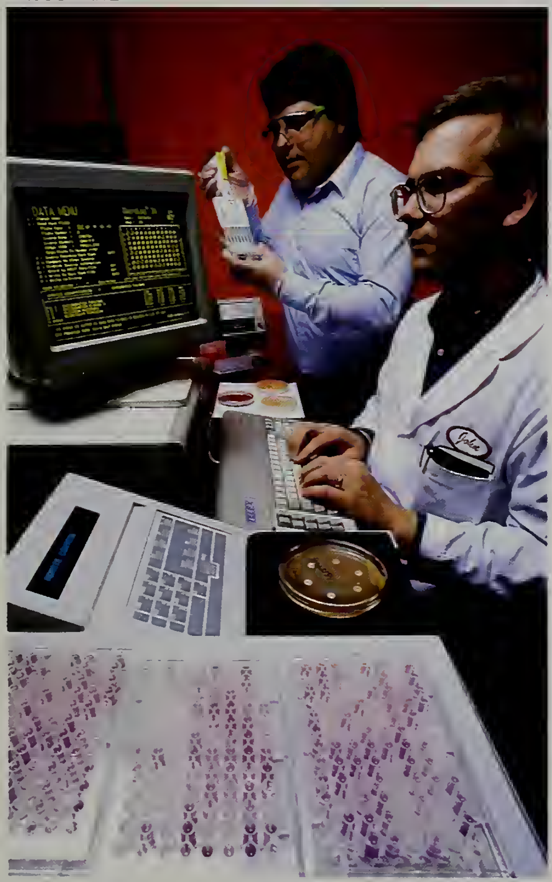
Doney points to a devastating fungus-transmitted virus disease of sugarbeets, *Rhizomania*, first discovered in the United States in 1983.

From germplasm collected by Coons in his plant explorations more than 50 years ago, ARS plant geneticist Robert T. Lewellen and colleagues at Salinas, California, recently developed breeding lines that resist *Rhizomania*, along with virus yellows, powdery mildew, and other important sugarbeet diseases. Commercial sugarbeet varieties derived from these lines may be available in 6 to 8 years.

GARRY SMITH

In studies to control sugarbeet root maggots, plant physiologist John Eide applies Bt solution.

BRUCE FRITZ



Using a computerized database, plant physiologist John Eide (foreground) and molecular biologist Chris Wozniak identify bacteria collected from sugarbeet maggots and from around sugarbeet roots. (K5173-1)

During the past 5 years, Doney and researchers with North Dakota and Texas agricultural experiment stations, Beet Sugar Development Foundation, and ARS laboratories in Fort Collins, Colorado, and Salinas, California, have evaluated about 400 accessions from the collection at Ames for traits that might benefit the sugarbeet industry.

Doney also breeds exotic germplasm to produce more sugar and impart hybrid vigor. He hopes to increase genetic diversity of sugarbeets used in advanced breeding programs.

Diversity of genes in present-day commercial hybrids is low, Doney says. Beet sugar-processing technology is less than 200 years old, and early selective breeding was narrowly focused on sugar yield. Before then, *Beta* species were cultivated as red garden beets, leafy vegetable beets, Swiss chard, and fodder beets.

In several overseas trips, Doney has explored native habitats for *Beta* germplasm, searching mostly near the Mediterranean Sea, but also in northern and eastern Europe.

His latest expedition was to Egypt in 1992, to find out whether many wild beets were left in Egypt's intensively farmed areas.

He reports, "We found lots of them because farmers have grown wild beets as a leafy vegetable for many centuries along Middle Egypt's Nile. And in the Nile Delta, where beets are regarded as weeds, seeds have been dispersed along many canals and ditches."—By **Ben Hardin,** ARS.

To contact scientists mentioned in this article, write or telephone Ben Hardin, 1815 North University St., Peoria, IL 61604. Phone (309) 681-6597, fax (309) 681-6690. ◆

Defining Mineral Needs of Pregnant Cows

Everyone knows the recipes by heart: "snips and snails and puppy-dogs' tails" for boys, "sugar and spice and everything nice" for girls. Now William A. House and Alan W. Bell have a recipe for healthy dairy calves, too.

House is a research animal physiologist at ARS' U.S. Plant, Soil, and Nutrition Laboratory at Ithaca, New York. He and animal science professor Bell of Cornell University teamed up in 1992 to produce a complete profile of fetal mineral content for dairy cattle, including a look at how the proportion of various minerals changes as the fetus progresses through gestation.

This information is important to cattle producers who want to ensure that they're feeding the right amounts of minerals to pregnant dairy cows to ensure the birth of healthy calves.

"For example, pregnant cows absorb about 45 percent of the calcium in their diet," House explains. "The absorbed calcium is used by the cow to maintain her own body and to support the growth of the fetus.

"We estimate that a 1,600-pound cow needs 12 grams of calcium per day for maintenance. Also, we know that the fetus needs 10 grams of calcium each day in late gestation. Since the dry pregnant cow absorbs less than half the calcium in her feed, she needs to be eating about 50 grams of calcium per day to meet her 22-gram requirement."

House and Bell analyzed the mineral content of fetuses taken from 19 pregnant 1,600-pound Holstein cows slaughtered at 190 to 270 days after conception. The gestation period for Holsteins is about 280 days.

Before House and Bell began their cooperative study, only calcium and phosphorus content of the dairy fetus had been measured, back in 1950. More complete analyses of mineral content had been completed for beef cattle, pigs, and sheep, according to House.

KEITH WELLER

ARS animal physiologist William House (left) and animal science professor Alan Bell of Cornell University display a 2-week-old Holstein heifer calf born from a cow in the nutrient study. (K5177-1)

He and Bell measured not only calcium and phosphorus content in the dairy fetus, but also levels of potassium, sodium, magnesium, iron, zinc, copper, and manganese.

Measurements took into account the entire "conceptus"—the fetus itself, plus fetal membranes, fetal fluids, and placental tissue.

"At day 200 of gestation, the fetus is depositing about 2 grams of calcium and 1.3 grams of phosphorus per day," says House. "At day 270, the calcium has increased to about 10 grams and the phosphorus to nearly 5 grams."

House attributes the increase in deposition of fetal calcium and phosphorus during late pregnancy to the accelerated rate of accumulation of these minerals in bone.

Concentrations of magnesium also increased with fetus age, House notes, while concentrations of potassium and sodium decreased.

During the latter stages of gestation, the bovine conceptus each day accrues an average 0.2 grams of magnesium, 1.0 grams of potassium, 1.4 grams of sodium, 18 milligrams of iron, 11.7 milligrams of zinc, 1.6 milligrams of copper, and 0.3 milligrams of manganese, House reports.

"The general practice among producers is to manage dairy cows to 'dry off'—so they're putting their energy into producing a fetus rather than producing milk," House says. "The nutritional requirements of the dry cow haven't gotten a lot of attention in the past.

"Now we have a data set that gives us a better understanding of mineral nutritional requirements of dairy cows during this phase."—By **Sandy Miller Hays**, ARS.

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Fighting the Insect Enemy in Somalia

ARS research provides ammunition against malaria, other diseases

SGT. DANIEL HART / U.S. ARMY

Permethrin-sprayed clothing protects U.S. soldiers from insects in Somalia.

When he arrived in Somalia last December, Lt. Armando Rosales was just as concerned about buzzing insects as he was about whistling bullets.

As a participant in the Operation Restore Hope mission to bring food to starving Somalis, Rosales faced an array of deadly insects. In Somalia, mosquitoes transmit a parasite that causes malaria, a disease that can be as fatal as a warlord's well-placed bullet. Ticks, flies, and other insects also spread dangerous diseases.

As a medical entomologist with the Armed Forces Pest Management Board in Washington, D.C., Rosales was well aware of those dangers when he arrived in Somalia for a 3-month tour with a medical team assisting an engineering squadron.

Within minutes after landing on Dec. 17, Rosales instructed the 70 people in the squadron to spray their clothing and bed mosquito nets with permethrin—an insecticide—and to cover their exposed skin with a cream containing a repellant called deet.

"I considered those to be the number-one defense against insect-borne disease," he says. "And, to my knowledge, when we left on March 7, there were no cases in our squadron."

That's good news to Carl E. Schreck and fellow Agricultural Research Service scientists who have developed deet and permethrin to protect soldiers. ARS scientists discovered deet in the 1950's and began developing permethrin in the 1970's. It's also good news for U.S. forces in Somalia, because an ARS computer model predicted that thousands of soldiers would have gotten malaria without the protection that deet and permethrin gave.

Schreck, an entomologist with the agency's Medical and Veterinary Entomology Research Laboratory in Gainesville, Florida, says soldiers now use deet cream that lasts longer than the earlier liquid form that sometimes irritated the skin. The cream was developed in the late 1980's under an ARS, military, and private-sector project.

"In field studies, deet cream has been effective for 7 to 10 hours under worst-case conditions in the Florida Everglades, where mosquitoes and other insects are numerous," Schreck says.

Campers and other people who love the insect-infested outdoors are also benefiting from deet in commercial insect repellants. Of the 212 products the U.S. Environmental Protection Agency has registered for this purpose, 192 contain deet.

Permethrin—a synthetic form of the natural pyrethrum insecticide—doesn't cause irritation, is odorless, resists breakdown in sunlight, and doesn't readily come out when clothes are washed. Soldiers can spray it on their clothing, netting, and tents, or it can be soaked into the material. "If you're wearing permethrin-treated clothes, you're a walking mosquito killer," Schreck says.

A division of the Graniteville Company, a South Carolina textile mill, has received a patent to make a tent fabric coated with permethrin.

The deet and permethrin protections appear to have been effective—not only in Rosales' squadron, but also among U.S. forces overall. As of mid-March, there were only 47 confirmed cases of malaria among U.S. troops in Somalia, according to an Army Surgeon General report.

"Most cases were because people didn't use the deet cream or permethrin material or didn't take anti-malarial drugs," Rosales says.

The ARS computer model had predicted that if no preventive measures had been taken, there could have been as many as 3,000 cases of malaria among 16,000 troops stationed in Baidoa and more than 7,000 cases in Mogadishu over a 60-day period. The malaria simulation model (MALSIM), developed by agricultural engineer Danel G. Haile at the Gainesville lab, predicts how many cases of malaria can be expected based on weather patterns, control measures, personal protection, and other factors.

MALSIM's numbers for Somalia show how dangerous it could be for U.S. troops there—if not for deet and permethrin. "As long as they use these properly, they shouldn't have a problem," Schreck says.—By **Sean Adams,** ARS.

Carl E. Schreck and Danel G. Haile are at the USDA-ARS Medical and Veterinary Entomology Research Laboratory, 1600 SW 23rd Drive, Gainesville, FL 32604. Phone (904) 374-5900, fax number (904) 374-5834. ◆

Berry Delightful!

Home gardeners and commercial strawberry growers can now ask for two ARS-developed strawberry varieties by name at plant nurseries in the Pacific Northwest. The juicy, bright red berries, Redgem and Bountiful, are intended for processing into preserves or adding to pies, ice cream, yogurt, or other foods.

Redgem also works well for backyard gardens or local fresh-market sales, says plant breeder Francis "Whitey" Lawrence, recently retired from ARS' National Clonal Germplasm Repository in Corvallis, Oregon.

Lawrence developed the berry plants and put them through about 10 years of testing in cooperation with the agricultural experiment stations of Washington, Oregon, and Idaho. He says the berries are well-suited for those states. The region's growers produced about 72 million pounds of strawberries, worth about $26 million, in 1992.

Both strawberry varieties bear fruit in June and have several qualities important to food processing. Unlike fruit that becomes soft and squishy when thawed, Redgem and Bountiful berries retain much of their original shape, texture, and attractive color after being frozen. Both did well in drip tests: To see if they would lose too much of their juice, frozen berries were placed on screens and allowed to thaw.

USDA

The berries are easy to cap; that is, their stems and green, leaf-like caps are easy to remove from the ripened fruit.

Bountiful is a good candidate for mechanical harvesting because most of its fruit can be gathered with only two harvests. Typically, commercial strawberry varieties produce berries that ripen at different times and so require three or more pickings.

Most Pacific Northwest strawberries today are picked by hand, though growers are interested in mechanizing future harvests to cut costs. The ultimate in efficient, economical harvesting would be a plant that needs only one harvest. "Bountiful might be used as a parent of the ideal, one-harvest strawberry of the future," says Lawrence.

The berries are relatives of two varieties bred primarily for East Coast and Midwest growers by ARS berry breeder Gene J. Galletta at Beltsville, Maryland.—By **Marcia Wood,** ARS.

Francis J. Lawrence is a collaborator with the USDA-ARS National Clonal Germplasm Repository, 33447 Peoria Road, Corvallis, OR 97333. Phone (503) 750-8712, fax number (503) 750-8717. ◆

Medflies Prefer Less-Acidic Bait

Luring Mediterranean fruit flies into traps can be enhanced by lowering the acidity of a commercial bait, ARS researchers report.

Reducing the acidity of the bait, NuLure, by increasing the pH from 4.5 to 8.8 attracted almost twice as many female flies into the test traps.

Baited traps are used to monitor medfly outbreaks and to capture the insects, says Robert Heath, a chemist at the ARS Insect Attractants, Behavior, and Basic Biology Research Laboratory in Gainesville, Florida.

Heath says lowering the bait's acidity affects the mixture of chemicals that lure medflies, but researchers are conducting further studies to confirm that preliminary finding.

California, Florida, and other citrus-producing areas have been forced to spend millions to eradicate the medfly so that fruit can be exported to other countries that want to keep medflies out.

During the medfly outbreak in the summer of 1992, California began considering the use of lower-acid NuLure bait in its medfly monitoring program, Heath says.

While that's bad news for medflies, it's good news for the public, Heath says. The improved bait does less damage to paint on automobiles and other surfaces. Bait mixed with an insecticide is often dispersed from the air during eradication programs and has resulted in complaints from citizens when droplets cause damage.—By **Sean Adams,** ARS.

Robert Heath is at the USDA-ARS Insect Attractants, Behavior, and Basic Biology Research Laboratory, P.O. Box 14565, Gainesville, Florida 32604. Phone (904) 374-5735, fax number (904) 374-5781. ◆

Science Update

New Low-Fat Mozzarella for Pizza

In May, pizza made with ARS' new low-fat mozzarella passed its first unofficial taste test, with hundreds of children at two Philadelphia schools. USDA's Food and Nutrition Service is evaluating the new cheese as a potential addition to the department's School Lunch Program. Compared to whole-milk mozzarella, the new cheese has about 60 percent less fat and salt and 40 percent more protein and calcium. It also has superior "meltability" to low-fat mozzarellas now on the market. *Edyth L. Malin, USDA-ARS Eastern Regional Research Center, Philadelphia, Pennsylvania. Phone (215) 233-6444.*

ARS Helps Grape Growers With Vineyard Viruses

Several grapevine viruses have shown up since 1991 in many replanted California wine vineyards and, more recently, in table and raisin grapevines. Many infected vines die. The ARS scientist who diagnosed the problem is now ranking vine rootstocks for virus susceptibility. She also hopes to devise faster diagnostics. It's too soon to know if viruses will affect table and raisin grape production in the nation's top grape-growing state. Biggest financial threat is to small wineries that have already replanted once to replace vines attacked by a root-feeding insect. *Deborah Golino, USDA-ARS Crops Pathology and Genetics Research Unit Davis, California. Phone (916) 752-4568.*

Stain Removers From Oilseed Crops

Biodegradable, oil-absorbent stain removers have been formulated from farm commodities such as peanuts and soybeans. The new cleansing agents remove fabric stains including motor oil, catsup, mustard, ink, lipstick, and mascara. Scientists are seeking a patent on the discovery. *Remon F. Joubran, USDA-ARS Eastern Regional Research Center, Philadelphia, Pennsylvania. Phone (215) 233-6453.*

New Peppers Have Ornamental Pizzazz

Blood-red, Tabasco-like peppers can't be missed on three ornamental breeding lines. The foliage of each line contains unique blends of purple, green, and white pigmentation. The peppers are edible but pungent. Fruit of two lines are borne singly and in clusters of two or three. The other line produces numerous clusters, with 10 to 15 peppers per cluster. All three succeeded in trials as bedding plants in Illinois and Japan and as potted plants in California. *John R. Stommel, Vegetable Laboratory, Beltsville, Maryland, phone (301) 504-5583; Robert J. Griesbach, USDA-ARS Florist and Nursery Crops Laboratory, Beltsville, Maryland. Phone (301) 504-6574.*

When a Disease Gets Sick, Will Melons Stay Healthy?

Viruses may prove to be a new way to use nature to quell bacterial diseases of crops. One such virus, a type known as a phage, attacks *Erwinia ananas* bacteria that cause brown spot disease, which can strike harvested honeydews and cantaloupes in Texas and California. Phages are harmless to people, animals, plants, and insects. But when a phage injects its genetic material into a bacterial cell of *E. ananas*, the cell obediently cranks out more phage particles until it bursts. Tests this summer are seeing if phages can prevent brown spot from taking hold in harvested melons. *Cynthia G. Eayre, USDA-ARS Crop Quality and Fruit Insects Research Unit, Weslaco, Texas. Phone (210) 565-2647.*

Jojoba Toxin Disarmed by Bacteria

Bacteria discovered by ARS scientists may lead to the use of jojoba meal as a cattle feed supplement. Jojoba is an oilseed crop now used in cosmetics. In studies, *Lactobacillus arizoniae* bacteria broke down natural toxins that, up to now, have made jojoba unsafe as cattle feed. *James L. Swezey, USDA-ARS National Center for Agricultural Utilization Research, Peoria, Illinois. Phone (309) 685-4011.*

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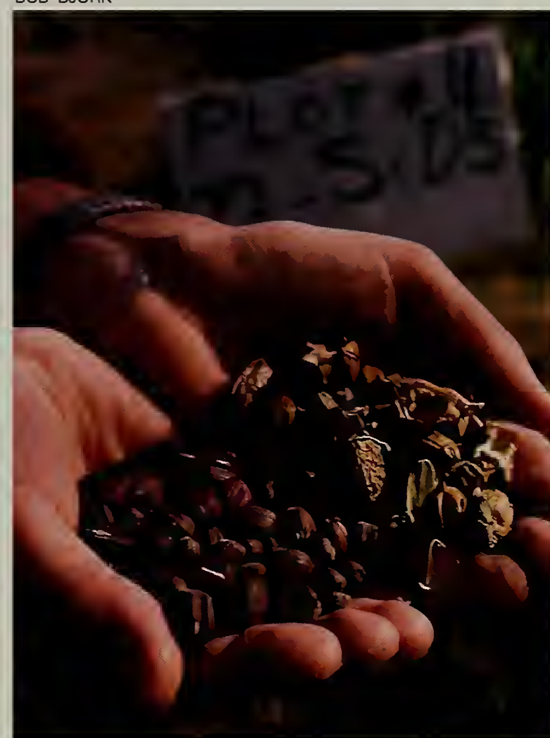

Jojoba seeds. (K903-1)

Pear Pest Falls to Fungi

Three fungi could become alternatives to insecticides against the worst insect pest of pears, the pear psylla. Scientists found the fungi infecting different psylla and aphid species. In lab tests, spraying the fungi—in a mix with oil or water—killed 100 percent of pear psylla within 5 days. The fungi are species of *Beauveria*, *Verticillium*, and *Paecilomyces*. *Gary J. Puterka, USDA-ARS Appalachian Fruit Research Laboratory, Kearneysville, West Virginia. Phone (304) 725-3451.*

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Upcoming in the September Issue

☛ ARS scientists in USDA's Water Quality Initiative work to make sure that "Don't drink the water!" isn't heard around America's farmlands.

☛ An inexpensive white powder called polyacrylamide helps stem soil erosion from furrow-irrigated farmlands. Crops do better, too, because water infiltration is improved.

☛ Though the "worm of death" is only a memory today for longtime U.S. ranchers, the flesh-eating screwworm is still a scourge to livestock and wildlife in parts of Central America and the Caribbean.